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AD A126835

THE FREQUENCY OF OCCURRENCE OF AIR MASSES OVER TWELVE EUROPEAN CITIES

JANUARY 1983

By

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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER: ASL-TR-0123
2. GOVT ACCESSION NO.: AD-A126835
3. RECIPIENT'S CATALOG NUMBER:
4. TITLE (and Subtitle): THE FREQUENCY OF OCCURRENCE OF AIR MASSES OVER TWELVE EUROPEAN CITIES
5. TYPE OF REPORT & PERIOD COVERED: Final Report
6. PERFORMING ORG. REPORT NUMBER:
7. AUTHOR(s): Marvin D. Kays, John T. Allen, and Louis D. Duncan
8. CONTRACT OR GRANT NUMBER(s):
9. PERFORMING ORGANIZATION NAME AND ADDRESS: US Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM 88002
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: DA Task 1L162111AH71
11. CONTROLLING OFFICE NAME AND ADDRESS: US Army Electronics Research and Development Command, Adelphi, MD 20783
12. REPORT DATE: January 1983
13. NUMBER OF PAGES: 46
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office):
15. SECURITY CLASS. (of this report): UNCLASSIFIED
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE:
16. DISTRIBUTION STATEMENT (of this Report): Approved for public release; distribution unlimited
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report):
18. SUPPLEMENTARY NOTES:
19. KEY WORDS (Continue on reverse side if necessary and identify by block number):

Air mass	Seasons
Cities	Occurrences
Maritime polar	Frequency
Continental polar	Weather chart

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Six different air masses that occur over twelve European cities are defined and discussed. The frequency of occurrence of the individual air masses over these cities over a period of several years was determined. The observations taken were reduced to monthly percentages. Continental polar and maritime polar were by far the most predominant air masses during the period of time studied. Continental polar was observed most frequently at seven of the cities and maritime polar most often at the other five cities, totaling 38

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20. ABSTRACT (cont)

percent and 34 percent, respectively. The other four air masses combined only totaled 28 percent on an overall basis. The inland cities experience more continental polar air while the western cities nearer the sea coasts are dominated more by maritime polar air masses.

Research related to maritime and continental aerosols and the influence of meteorological parameters upon aerosol particulates is described.

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INTRODUCTION

The effects of the atmosphere upon the attenuation of electromagnetic (EM) radiation has received considerable attention in the last ten years, especially in the Department of Defense (DOD). Systems such as target designators, target acquisition and guidance, and various radars are sometimes limited in their operations by obscuration caused either by man (smoke, track-dust) or by natural means (fog, rain, snow, etc).

Many researchers have published on the effects of the atmosphere upon visibility. State-of-the-art reports reflect the US Army's early interest in these atmospheric effects upon EM transmission at laser wavelengths. Consequently, field experiments and extensive measurement programs have been conducted for model development/validation. The US Army has conducted such experiments in order to observe the effects of dust, smoke, and battlefield induced contaminants on system performance. The US Navy has measurement programs to determine the characteristics of the marine aerosol. The Air Force, interested in the atmospheric effects upon the performance of precision guidance munitions, target acquisition and guidance systems, and directed energy systems have: (1) participated in a North Atlantic Treaty Organization (NATO) sponsored project, Optical Properties of the Atmospheric Quantities in Europe (OPAQUE); (2) gathered target and background data in the United States; and (3) conducted field experiments at several locations in the US and Europe during periods of fog with results that will be discussed later in this paper. (See Selected Bibliography for a list of supportive documentation.)

Because of the need for models to simulate and/or predict various atmospheric and obscuration effects upon EM propagation, the US Army Atmospheric Sciences Laboratory (ASL) has compiled models for optimal computer efficiency and accuracy. This library of models, known as the Electro-Optical Systems Atmospheric Effects Library (EOSAEL),[1] [2] is available to qualified users upon request.

Analysis of field test fog and haze data[3] revealed that if the data were grouped according to the prevailing air mass, then simple relationships could be developed between extinction coefficients at two different wavelengths. As a result of grouping the data according to air mass type, it became apparent that a climatological study of air mass types over Europe was needed. Certain characteristics can be inferred about the atmosphere and its effect upon EM propagation if the air mass is known or can be forecast. Characteristics of different air masses, their relationship to aerosols, and air mass frequency

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[1] R. C. Shirkey and S. G. O'Brien, editors, 1981, EOSAEL 80 Volume II User's Manual, ASL-TR-0073, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM

[2] R. G. Steinhoff, 1981, Supplement to EOSAEL 80 Volume II User's Manual, Program Listings for EOSAEL 80 and Ancillary Codes AGAUS and FLASH, ASL-TR-0073 (Supplement), US Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM

[3] Louis D. Duncan and James D. Lindberg, 1981, Air Mass Considerations in Fog Optical Modeling, ASL-TR-0075, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM

of occurrence over Western Europe will be discussed in the following sections.

AIR MASSES

History

The identification of an air mass as an analysis tool has declined in the US with the use of the computer for meteorological analyses and forecasts. Although meteorological text books that have been written in the last twenty years rarely mention air masses, discussions of air mass classification may be found in the earlier text books.[4 5 6 7 8]

The theory of air masses in the atmosphere was based upon research by Vilhelm F. Bjerknes, then professor at the University of Stockholm. In 1897 he perceived a theorem concerning circulation in fluids that led him to a synthesis of thermodynamics applicable to large scale motions in the atmosphere and in the oceans.[9]

The concept of air masses was enlarged upon by Tor H. Bergeron[10 11] who is generally given credit for the widely accepted system for characterizing air masses. Bergeron introduced a dual classification of air masses: a geographical classification relating to source regions and a thermodynamic classification depending on whether the air mass was colder or warmer than the underlying surface. Each of the four source regions, arctic, polar, tropical and equatorial, were then subdivided into maritime or continental classifications. This classification scheme has not always been used consistently as more identifying parameters have been determined to characterize the modification and changes of an air mass with time. The following description of air masses was taken from five references.[4 5 6 7 8]

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[4]F. A. Berry, E. Bollay, and Norman R. Beers, 1945, Handbook of Meteorology, McGraw Hill Book Co, Inc, New York

[5]Sverre Petterssen, 1940, Weather Analysis and Forecasting, McGraw Hill Book Co, Inc, New York

[6]Horace Robert Byers, 1944, General Meteorology, McGraw Hill Book Co, Inc, New York

[7]Hurd C. Willett, 1944, Descriptive Meteorology, Academic Press, Inc, New York

[8]Bernhard Haurwitz and James M. Austin, 1944, Climatology, McGraw Hill Book Co, Inc, New York

[9]Ralph Jewell, 1981, "The Bergen School of Meteorology," Bull of Amer Met Soc, Vol 62

[10]T. Bergeron, 1928, "Uber die Dreieimensional Verknupfende Wetteranalyse, Geof Pub, Vol V

[11]T. Bergeron, 1930, "Richtlinien einer Dynamischen Klimatogie," Met Zeitscher

Description

An air mass may be defined as a huge body of air whose conservative properties of temperature and moisture are more or less homogeneous in the horizontal direction. The horizontal homogeneity (uniformity of temperature and moisture content) is only relative in character. A typical continental polar (cP) air mass in North America may cover half of Canada and, in Asia, one-third of Siberia. They often extend 1600 miles from east to west and 1200 miles from north to south. For example, the weather of the entire area east of the Mississippi River can be influenced by a cold air mass moving southward out of Canada. Likewise, most of Europe can be influenced by the same type of air mass originating in Siberia or northern Russia. Having been over a cold land surface for several days, these air masses naturally bring colder temperatures. The types of clouds and the kind of weather that result from their incursion depend upon whether the air is stable or unstable (warmer or colder than the underlying surface).

For example, a maritime tropical (mT) air mass originating in the tropical latitudes of the Atlantic Ocean and reaching the west coast of Europe will bring moist air and warmer temperatures to the area. The weather associated with this air mass, also depends upon whether it is warmer or colder than the western European land mass over which it moves.

When a cP European air mass moves from east to west, it is conjectured that the further west it moves the more aerosols and the more different types of aerosols may be found within the air mass. This phenomenon lowers the visibility within the air mass both at the surface and for several thousand feet aloft.

When a maritime air mass moving over the ocean for several days invades the land surface of western Europe and the British Isles, most of the aerosols are sea salt particles. The visibility in these air masses is much higher than in a cP air mass.

An air mass in motion, one that constitutes a major outbreak of polar or tropical air, is modified to some degree as it progresses so that the advance portion of the air mass is no longer the same as the portion which remains near the source region. But the essential characteristics of the air mass lies in the fact that the horizontal gradients of moisture and temperature are small within the air mass compared with the gradients that occur within the transition zone between adjoining air masses. Modification of an air mass occurs whenever heat or moisture is added from the underlying surface, when turbulent transfer of heat and moisture occurs along the vertical, when subsidence occurs, or during the liberation of latent heat of vaporization.

Winter Air Masses

Figure 1* illustrates the trajectory of the major air masses over Europe during the winter season. Table 1** lists the major air masses, source

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*Figures appear after the text.

**Tables appear after the text.

regions and associated weather. A brief description of the six different air masses used in this report and the typical weather associated with them follows.

- Continental Arctic (cA) - cA air mass spreads over Europe from the northeast. Although east of the Baltic Sea it is frequently observed in winter, in Western Europe it is found in winter only occasionally. The coldest of all European air masses, many severe winters are associated with its abnormal westward displacement.

- Continental Polar (cP) - cP air mass originates over the continental regions of northern Russia, Finland and Lapland. It is found over Europe when a stationary or retrograde high pressure cell is centered over the northern Baltic regions and over northwestern Russia. Downslope effects often produce warm temperature on the Norwegian coast due to adiabatic compression. Occasionally in the spring and summer, high pressure settles over the Caspian and Black Seas bringing cP air into Europe through the Balkans and the Ukraine. Owing to the dryness of this air, clouds are usually absent over the continent. Fair weather cumulus clouds are typical when the air is over the British Isles. Over the Mediterranean the air becomes unstable, resulting in cumulus clouds with rainshowers. Occasionally, cP air initiates the development of deep cyclonic systems over the central Mediterranean area. Visibility is usually good. However after cP is modified, haze layers form and reduce visibility.

- Continental Tropical (cT) - cT air mass is only prevalent from April to October and seldom affects the weather of Europe during the remaining months of the year. Originating in northern Africa, it has more of an effect on southern Europe than on central Europe. When the cT air mass does reach central or northern Europe, it has changed considerably so that it is very similar to mT air. cT air is a major source of heat for the development of Mediterranean low pressure systems during the winter and spring months.

- Maritime Polar (mP) - mP is the predominant air mass of western Europe. It has somewhat variable properties, depending upon the local nature of the source and its trajectory before reaching Europe. mP air observed over Europe usually originates in the form of cP air over North America. It reaches the west coast of Europe by various trajectories and therefore is found in different stages of modification, producing weather similar to mP air over the west coast of North America. cP air that leaves North America and travels southeastward over the western Atlantic and then northeastward into Europe has had ample time to adapt its properties to those of the underlying ocean surface. Consequently, this air arrives as a relatively warm, humid air mass that is in a neutral or slightly stable state. All mP air mass invasions are characterized by a high frequency of cloudiness.

In the Mediterranean region, mP air enters mostly through southern France between the Pyrenees and the Swiss Alps. Sometimes mP air passes across the Mediterranean, across Syria and down the Euphrates Valley to the Persian Gulf and into the Arabian Sea as far as the northwestern coast of India.

• Maritime Arctic (mA) - mA air sweeps into Europe almost directly from the north which usually means the presence of an intense low in Central Europe with a long north-south axis. Strong outbreaks of mA air, originating in the Arctic between Greenland and Spitsbergen, usually follow in the wake of a deep cyclonic (low) system moving across Scandinavia. A deep cold high pressure system generally moves into the area behind the cyclonic system and is generally associated with the invasion of mA air.

By the time the mA air reaches the British Isles, it is very unstable. Cumulus clouds and widespread showers and squalls are frequent. Visibility is usually good because of the turbulence. The mA air will sweep over France to the Mediterranean whenever a secondary low system develops over France and Belgium. Frequently, heavy snows in the Alps and in other exposed highlands are observed with an mA air mass.

• Maritime Tropical (mT) - mT air that arrives over Europe usually originates over the southern portion of the North Atlantic under the influence of the Azores high pressure system and is marked by pronounced stability in the lower levels. Relatively high temperatures and moisture content accompany this influx of air. Visibility is reduced because the air is stable or in the presence of fog and drizzle. mT air is most frequently observed in western Europe and by the time it reaches higher latitudes, it is forced aloft over colder air at the surface.

Summer Air Masses

The trajectory of air masses over Europe in the summer season is shown in figure 2.

• cA - cA air is rarely found over Europe in the summer months.

• cP - Cool cP air masses are confined mostly to high latitudes. It is a dry air mass with generally fair weather over the continent and the British Isles. The visibility is usually reduced with haze and smoke because of slightly stable conditions. As it moves southward, the lower layers become unstable and, eventually, clouds and showers develop.

• cT - The broad low latitude continental regions of North Africa provide an ample source region for true cT air. In the source region, the air is unstable but very dry. As the air moves northward into Europe, its moisture content increases by evaporation from the Mediterranean Sea and from land areas. This addition of moisture to an unstable air mass causes showers and thunderstorms.

• mP - mP air is cooled by the ocean during its long west to east trajectory and brings good weather to western and northwestern Europe. Occasionally, because of surface heating, an isolated shower or thunderstorm is observed over land during the daytime hours.

• mA - mA air masses are so shallow in the summer they are quickly modified and can no longer be identified as a separate entity.

• mT - mT is a rather stable air mass that becomes less stable over land during the day because of surface heating. It is characterized by low clouds and fog. Over the water, sea fogs occur in the approaches to the English Channel during spring and early summer. This type of air mass is observed during the summer season when the Atlantic subtropical high pressure system extends across Europe.

The influence of topography on the movement and modification of air masses can be summarized as follows:

(1) The relative warm maritime air can invade the entire land of Europe because of no north-south mountain barriers.

(2) The west-east mountain chains that extend across southern Europe separate the warm southern region from the cooler lands to the north.

(3) The numerous seas and gulfs scattered throughout the continent provide additional moisture sources.

(4) The flatness of eastern Europe and Russia induces cold continental air to spread westward and produce extended periods of cold weather.

AEROSOLS

An aerosol is a system of colloidal particles dispersed in a gas. Many reports and books have been written describing the different sources, size distributions and aerosol particles and their effects upon pollution, clouds, visibility, etc. One of the most recent books which contains some of the latest information on aerosols is by Pruppacher and Klett.[12] Our study will concentrate only on the relationship between the aerosol and air masses or continental/maritime influences on the aerosols.

Twomey and Wojciechowski[13] have shown that continental air masses contain more cloud nuclei than maritime air masses and that the median of cloud nuclei over the open ocean varied little from region to region. The time of delay from continental to maritime levels of concentration is about three days. This indicates that an ocean measurement site could be 100 miles from shore and measure continental type aerosols. On the other hand, an inland site could measure maritime aerosols. This phenomenon was observed and documented at San Nicolas Island in a report by Rosenthal.[14] He stressed that no matter where elctro-optical/meteorological measurements are conducted, air mass sources must be determined. Air mass flow pattern analyses were performed based on trajectory analysis and synoptic-mesoscale considerations.

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[12]Hans R. Pruppacher, and James D. Klett, 1978, Microphysics of Clouds and Precipitation, D. Reider Publishing Co, Dortrecht, Holland

[13]S. Twomey and T. A. Wojciechowski, 1969, "Observations of the Geographical Variation of Cloud Nuclei," J Atmos Sci, Vol 26

[14]J. Rosenthal et al, 1979, "Summary Marine/Continental History of Aerosols at San Nicolas Island During CEWCOM-78 and OSP III," TP-79-32, Pacific Missile Test Center, Point Mugu, CA

Aerosol data taken in the North Sea[15] revealed that as an air mass leaves a continental area for the open sea, air mass modification takes place as the continental aerosol component is decreased. In addition, a new source of aerosols produced by the sea comes into play.

Fitch and Cress[16] reported on measurements of the number and size distribution of aerosols that have been made by aircraft at constant altitudes over France, Denmark and West Germany. They found that a maritime air mass produced good visibility and that particle counts were so low in the mixing layer that a distinct accumulation mode was not evident.

Deirmendjian,[17] in a report to the US Army Research Office, states that the values of aerosol parameters depend upon many variables. Besides the usual meteorological parameters such as temperature, pressure, humidity, and wind, one needs data on the local and surrounding terrain and on types of air masses and their history before arriving over the site.

Aerosol measurements made by aircraft of stratocumulus clouds nucleated by maritime aerosols and by urban fog in the Los Angeles area have been reported by Barrett, Parungo and Pueschel.[18] They found that clouds nucleated by maritime aerosol had spectra which were heavily skewed toward larger drop size while urban smog clouds were dominated by small particles. Measurements made of aerosol concentration in the frontal zones in Russia[19] showed that the aerosol concentration decreased with a cold frontal passage and increased during a warm frontal passage. The changes were of three orders of magnitude.

Experiments have been made to study the relationship between visibility and relative humidity. Buma[20] reports of such an experiment at Leeuwarden, Netherlands, in which the data were categorized by surface wind direction as

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[15]S. G. Gothman and B. G. Julian, 1980, "Passive 19.3 GHz Radiometer and Aerosol Data From the North Sea During MARSEN I, Sep-Oct 1979," NRL Memo Report 4285, Navy Research Laboratory, Washington, DC

[16]Bruce W. Fitch and Ted S. Cress, 1981, "Measurements of Aerosol Size Distribution in the Lower Troposphere Over Northern Europe," AFGL-TR-80-0192, University of California at San Diego, Scripps Institute of Oceanography, Visibility Laboratory, SIO Ref 81-18

[17]D. Deirmendjian, 1980, Aerosol Modelling for Optical Weather, Final Report, Rand Corporation, US Army Research Office, Durham, NC

[18]E. W. Barrett, F. B. Parungo and R. F. Pueschel, 1979, "Cloud Modification by Urban Pollution: A Physical Demonstration," Meteorol Rundschau, Vol 32

[19]N. M. Kireyeva, G. B. Mashkova and N. P. Yasevich, 1976, Change in the Concentration of Atmospheric Aerosols with the Passage of Fronts, Trudy Institut Eksperimental Noy Meteorologei, Seriya Fizika Nizhney Atmosfery, Issue 12(31), Moscow, ADB051552, trans Foreign Tech Div

[20]T. J. Buma, 1960, "A Statistical Study of the Relationship Between Visibility and Relative Humidity at Leeuwarden," Bull Amer Met Soc, Vol 41

being either from the continent or from the ocean. Periods from October 1956 to May 1957 and September 1957 were investigated. He found that the visibility was much lower when the wind was from the land than when it was from the sea at the same humidity. With relative humidity of 90 percent, the probability of the visibility being less than 7 km is 92 percent in continental air, whereas this probability is only 29 percent in maritime air. Later work by Van de Van[21] verified Buma's findings that the visibility at a given relative humidity is much worse when continental air is present than it is for maritime air. He found that the probability of a visibility being less than 10 km, at a relative humidity of 90 percent, is 84 percent for continental air and 52 percent for maritime air. The larger number of particles present in the continental air masses along with the presence of an inversion and thick mixing layers may account for this.

Studies have been made comparing the growth of aerosols with changing relative humidity.[22 23 24] Theoretical and observed continental and maritime aerosol growth rate was plotted against relative humidity. An 80 percent relative humidity value was reached before much aerosol growth was noticed; a 95 percent humidity value was reached before that aerosol growth rate became exponential.

An extensive field program (Meppen 80) was designed to provide a major data base of specialized microphysical, optical, and meteorological measurements for researching special problems in the performance of various kinds of visible and electro-optical systems in low visibility wintertime conditions in Europe. Aerosol measurements were made on the ground and made aloft by an instrumented tethered balloon. Results reported by Lindberg[25] of vertical profiles of liquid water content and extinction coefficients show a layered structure of clouds and haze. Data previously taken in Germany were grouped

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[21]M. J. M. Van de Van, 1978, Aerosol Measurements During Spring 1978: Their Size Distributions and Optical Properties in Visible and Infrared Wavelength Regions, Report PHL 1978-41, Physics Laboratory of the National Defense Organization TNO, The Hague, Netherlands

[22]R. D. H. Low, 1968, "A Comprehensive Report on Nineteen Condensation Nuclei and Aerosol Particles as a Function of Its Dry Size and Composition and the Relative Humidity," J Appl Meteorol, Vol 14

[23]Gottfried Hanel, 1976, "The Properties of Atmospheric Aerosol Particles as Functions of the Relative Humidity at Thermodynamic Equilibrium with the Surrounding Moist Air," Advan in Geophys, Vol 19, Academic Press, New York

[24]J. W. Fitzgerald, 1975, "Approximation Formulas for the Equilibrium Size of an Aerosol Particle as a Function of its Dry Size and Composition and the Relative Humidity," J Appl Meteorol, Vol 14

[25]James D. Lindberg, 1981, "Atmospheric Effects on Electro-Optical, Infrared, and Millimeter Wave Systems Performance," Proceedings of SPIE - The International Society for Optical Engineering, Vol 305, (Bellingham, WA: Society of Photo-Optical Instrumentation Engineers)

according to air mass occurrence by Duncan and Lindberg,[3] and the Meppen 80 data were used to validate their vertical extinction-air mass model.

Nilsson[26] showed that variations in humidity affect the aerosol extinction through modification of the particle size distribution and that the size and number distribution are different for different air masses. He calculated extinction coefficients for five different air masses and four different visibility values assuming size distributions according to air mass type. He assumed that arctic air was very clean and the total number density of aerosols would be low. On the other hand, a tropical air mass has a great number of small particles which would give a very high number density. A maritime air mass contains sea salt particles in the coarse particle mode. Pinnick et al[27], from eight days of wintertime West Germany data, found a size-distribution-independent linear relationship between particle extinction coefficient and liquid water content at 10μm. Air mass analysis was not available when Pinnick's report was published.

The type of air mass dominating an area is very important in performing optical modeling and also in determining the optical properties of the air. Since the United States and NATO military forces are relying increasingly on new sophisticated weapons systems employing electro-optical sensors or systems, it is vitally important for the researcher to know the classification of the air mass. The logical approach is to characterize the optical properties of the different air masses in order to develop optical models that can be used for evaluation of systems performance.

Air masses are generally characterized by temperature and moisture content. Since the various air masses originate over distinctly different regions of the earth's surface, a reasonable hypothesis is that each air mass contains aerosols and condensation nuclei distinctly different in composition and sizes from those of other air masses. It follows, then, that the various air mass types can be expected to possess different microphysical and optical properties.

AIR MASS FREQUENCY

Data and Results

The data used to determine frequency of air masses over Europe were obtained from daily weather charts published by the University of Free Berlin. The publication contains the European surface, 850-mbar, 700-mbar, 500-mbar analysis, forecasts, and upper air data for the Berlin-Tempelhof Airport. The

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[3]Louis D. Duncan and James D. Lindberg, 1981, Air Mass Considerations in Fog Optical Modeling, ASL-TR-0075, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM

[26]Bertil Nilsson, 1979, "Meteorological Influence on Aerosol Extinction in the 0.2 - 40μm Wavelength Range," Appl Opt, Vol 18

[27]R. G. Pinnick et al, 1978, "Vertical Structure in Atmospheric Fog and Haze and Its Effects on Visible and Infrared Extinction," J Atmos Sci, Vol 35

850-mbar analysis also contained an air mass for that level. The air mass analysis at the 850-mbar level was used as a guide in determining the air mass classification at the surface. The history and position of pressure centers, fronts, and values of temperatures were also considered. Geb,[28] from the University of Free Berlin, classified eighteen different air masses for Middle Europe using the surface character and latitude of the source region, stability and turbidity of the air mass, and the temperature of the air in relation to the underlying surface. He developed an analysis scheme using the 850-mbar equivalent potential temperature or the maximum daily temperature to differentiate between air masses. Geb's classification was too detailed for our purpose and many of the air masses in his scheme occur infrequently. Hence, the air masses were categorized into six different and distinct air mass types based upon main source regions and trajectories and their frequency of occurrence. The six different air masses used in this report were discussed earlier and listed in table 1. The twelve locations and the number of air mass determinations for each location are listed in table 2. The location of each city is shown on a map in figure 3.

The frequency of occurrence for each of the six air masses was computed by months for the twelve cities listed in table 2. The monthly values of frequency of occurrence of air mass types for each city are given in tables 3 to 14. Frequencies of occurrence were also computed by seasons with the winter season comprised of December, January and February; spring - March, April and May; summer - June, July and August; and fall - September, October and November. These seasonal computations are listed in tables 15 through 17 by cities and seasons and table 18 lists the annual frequency of each air mass for each city. Figures 4 through 7 depict the seasonal frequency of the different masses for the twelve cities and the following discussion will be concerned with these particular figures.

- Winter (figure 4). The western cities of Meppen, Cherbourg, Lyon and Madrid are in a favorable location to experience the influx of maritime air, and this is exactly what happens. The cities of Brussels and Tubingen had an almost equal amount of continental and maritime air while Berlin experiences more continental air. The southernmost city of Tirane also is subjected to equal amounts of the continental and maritime air. Helsinki experiences a larger frequency of cA and mA air than any other city--mainly because it is closer to the arctic air source. Continental tropical air occurs infrequently in the winter season in almost all of the cities except Madrid.

- Spring (figure 5). The transitional months from winter to summer undergo a few strong surges of air from the north, but there is generally a decrease in the cA air as seen in Helsinki. The mP air increases over the western cities and decreases over Tubingen, Kiev, and Warsaw. The decreasing mP air is replaced by an increase of cP air. There is an increase of cT air over Budapest and Tirane and the flow aloft becomes more southerly.

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[28]M. Geb, 1973, Die Anwendung der Objektivierten Luftmassen-Klassifikation für Mitteleuropa, Beilage zur Berliner Wetterkarte, des Instituts für Meteorologie, der Freien Universitat Berlin, Berlin, FRG

• Summer (figure 6). The influx of cT air is very apparent over the inland and southern cities. At Madrid, Tirane, Budapest and Kiev the average amount of cT air masses increases from 19 percent in the spring to 38 percent in the summer. There is no appreciable change in the amount of cP air at Meppen, Cherbourg or Lyon, but there is a reduction on an average of 6 percent at the other nine cities. It reduces from 46 percent to 40 percent.

Maritime polar air continues to dominate at most of the cities with the three cities of Meppen, Tubingen and Brussels averaging 61 percent for this particular air mass. Continental arctic air masses are almost nonexistent reducing from an average of 4 percent in the spring to less than 1 percent in the summer. Helsinki is the only city that has considerable cA air at any time of the year. The frequency decreases from 25 percent in the spring to 5 percent in the summer at that city.

• Fall (figure 7). Brussels, Meppen and Cherbourg continue to be dominated by the mP air. Kiev and Warsaw experience a domination of cP air. The southern cities of Tirane and Madrid have a decrease of cT air in the fall as compared to summer, but cT still occurs approximately 30 percent of the time at each city. The northern city of Helsinki is practically void of any tropical air during this season.

Figure 8 depicts the annual frequency of occurrence of each air mass and is a useful source from which to draw generalities. However, it should be used with caution whenever seasonal or monthly time interval statistics are needed. Figure 8 generally illustrates that the southern cities experience cT air, the western cities more mP air, and the inland cities and the northern city (Helsinki) have had more cP air than any other air mass.

Identification of Air Masses

A need exists for identification of air masses without the use of the daily weather charts from the University of Free Berlin. Essenwanger[29] analyzed frequency distributions for temperature and water vapor pressure finding evidence for five different air mass types. Bryson[30] later developed a statistical approach referred to as a particle collective method for analyzing air mass frequencies based upon research by Essenwanger. Daily maximum temperatures were multimodel and appeared to be a mixture of normal curves with different mean characteristics. He was able to devise a graphical technique to separate the mixed normals. Davis[31] used a computerized cluster analysis technique to investigate the possibility of simplifying the European

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[29] Oskar Essenwanger, 1954, Neue Methode der Zerlegung von Haufigkeitsverteilungen, in Gauß'sche Normalkurven und Ihre Anwendung in der Meterologie, Berichte des Deutschen Wetterdienstez, Nr 10

[30] Reid A. Bryson, 1966, "Air Masses, Streamlines, and the Boreal Forest," Geographical Bulletin, Vol 8

[31] J. M. Davis, 1981, The Use of Cluster Analysis in the Identification and Characterization of German Air Masses, Internal Report, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM

air mass classification scheme. He examined the bivariate frequency distribution for equivalent potential temperature and mixing ratio at the 850-mbar level for Berlin and was able to detect four different air masses in January. Other researchers[12 13 14 15] indicate that the potential temperature, equivalent potential temperature, and the dry bulb temperature are normally distributed. Coleman[16] has applied an interactive computer technique for separating mixed normal distributions applied to air mass analysis. This method shows some promise to differentiate adequately between air masses by considering the equivalent potential temperature at the surface, 850-mbar, 700-mbar, and 500-mbar levels.

Another technique to categorize weather was started in Germany when a calendar of large scale weather types was prepared using European data from 1881 through 1939. The term large scale weather type means an atmospheric condition that remains nearly unchanged for a period of several days. The classification scheme was amended several times because of improvement in synoptic analysis and was updated in 1968 by Headquarters, 2nd Weather Wing[17] to include 86 years of data. The German Weather Service continues to classify weather patterns into the "Grosswetterlagen" (GWL).

The weather patterns are classified into three main types: zonal, mixed, and meridional flow. These three main types are subdivided into twenty-nine categories. The category occurring most frequently (16.7 percent) is the pattern that results in cyclonic westerly flow (code WZ) over Europe. The second most frequent pattern (12.0 percent) occurs whenever a well-defined closed high pressure system exists over Central Europe (code HM).

The characteristic weather associated with the WZ type is usually unsettled. Precipitation alternates with scattered clouds. Precipitation in the winter is rain; in the summer it is thunderstorms. Cool temperatures occur in summer and the winters are mild. The air mass identified as code HM brings the type of weather that affects electro-optical systems in winter. Although code HM

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[12]A. K. Showalter, 1939, "Further Studies of American Air Mass Properties," Monthly Weather Rev, Vol 67

[13]D. P. McIntyre, 1950, "On the Air Mass Temperature Distribution in the Middle and High Troposphere in Winter," J Meteorol, Vol 7

[14]R. Berggren, 1953, "On Temperature Frequency Distribution in the Free Atmosphere and a Proposed Model for Frontal Analysis," Tellus, Vol 5

[15]N. S. McDonald, 1975, "Eigenvector Analysis as an Aid to Air Mass Recognition," Arch Meteorol Geophys Biokilmatol, A, Vol 24

[16]Cranston R. Coleman, 1982, "An Interactive Computer Technique for Separating Mixed Normal Distributions Applied to Air Mass Analysis," Masters Thesis submitted to North Carolina State University, Raleigh, NC

[17]Catalogue of European Large Scale Weather Types From a Report of the German Weather Service in the US Zone No 33, Bad Kissingen, 1952, as Revised by 2nd Weather Wing, Military Airlift Command, US Air Force, 1968

weather is usually warm, fair and dry in the summer, ground fog, low stratus, and cooler temperatures occur in the cold season.

Essenwanger[11] used the GWL to evaluate models that predict fog and low clouds in Central Europe. He found that the best one-day prediction chances appear on the second day for some GWL types, but in general the one-day chances are high owing to the prediction of large scale phenomena in contrast to the local scale. He found that when a code HM was over central Europe, the cold air influx led to widespread reduction of visibility in the morning hours or to the formation of low clouds. Figure 9 is a typical example of a surface map during an HM type with the probable location of the associated air masses.

The use of the GWL could possibly replace air masses in characterizing aerosol characteristics with a weather phenomenon. Some of the 29 categories could be combined into 6 to 10 categories for easier analysis and higher frequency of occurrence.

SUMMARY

Although a large data base containing electro-optical/meteorological/aerosol data exists, this data base is fragmented over DOD and the civilian community and needs consolidating for optimum use. The US Army Atmospheric Sciences Laboratory has initiated an effort to consolidate the data for model validation and data analysis.

The concept of air masses was shown to be nothing new and is based upon atmospheric dynamic and thermodynamic laws. A particularly large air mass can cover two-thirds of the US. Aerosol size and number distributions that reduce transmission through the atmosphere are related to the different air masses. As a rule more particulate matter is found in continental air masses than in maritime air masses. The average lifetime of an aerosol in the lower 1.5 km is two to three days. This indicates that it takes two to three days for an air mass to modify if it is over an entirely different surface than its source region. The effects of meteorological parameters, such as relative humidity and direction the surface wind has upon aerosol growth rates and their number and size distributions, have been documented. These same meteorological parameters are also characterized by air mass: for example, a cA or a cP air mass is generally cold and dry with wind from the north, northeast, or east. An mT air mass is usually warm and moist with winds that are southerly in direction. Field tests have shown that the aerosol concentration at a station changed with frontal passages and changing air masses.

The western cities of Europe are dominated by the mP air masses that occur nearly 40 percent of the time. The inland cities experience more continental type air masses. Maritime air occurs at all of the cities at one time or another but only 8 percent of the time at Kiev. The southern cities of Tirane and Madrid receive more cT air than any other kind of air mass.

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[11] O. M. Essenwanger, 1973, On the Duration of Widespread Fog and Low Ceiling in Central Europe and Some Aspects of Predictability, TR-RR-73-9, US Army Missile Command, Redstone Arsenal, AL

Knowledge of the relationship between air masses and aerosol characteristics is not sufficient to provide all the necessary parameters in forecasting atmospheric transmission. However, knowledge of the existing meteorological conditions and air mass type does give an indication of the aerosol characteristics.

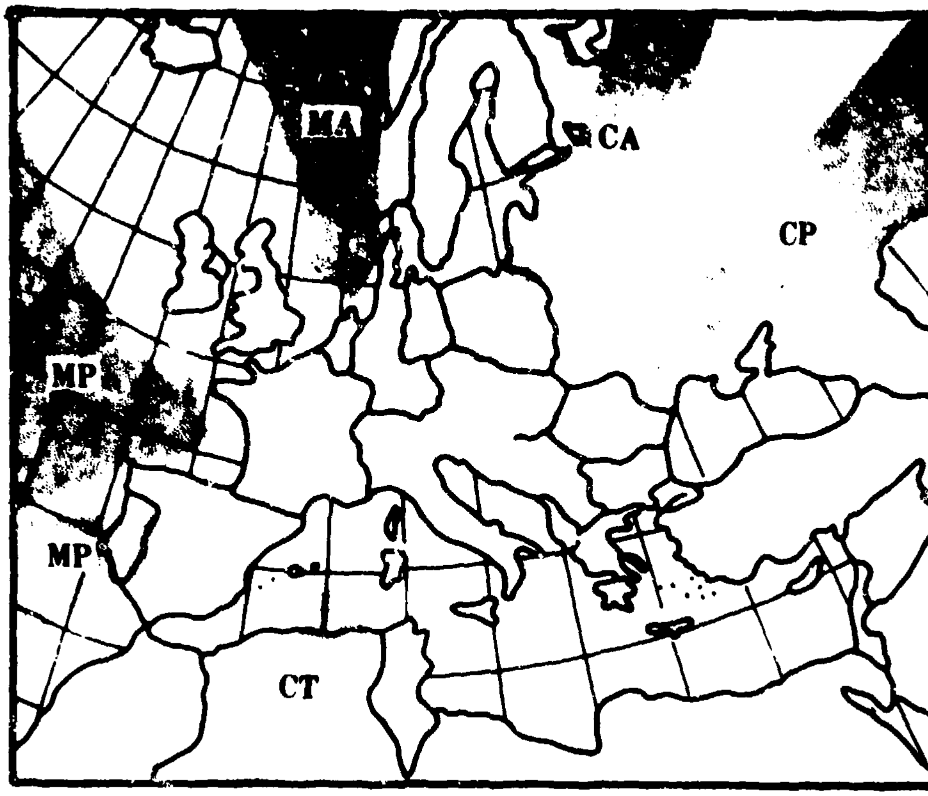

Figure 1. Trajectory of the major air masses during the winter.

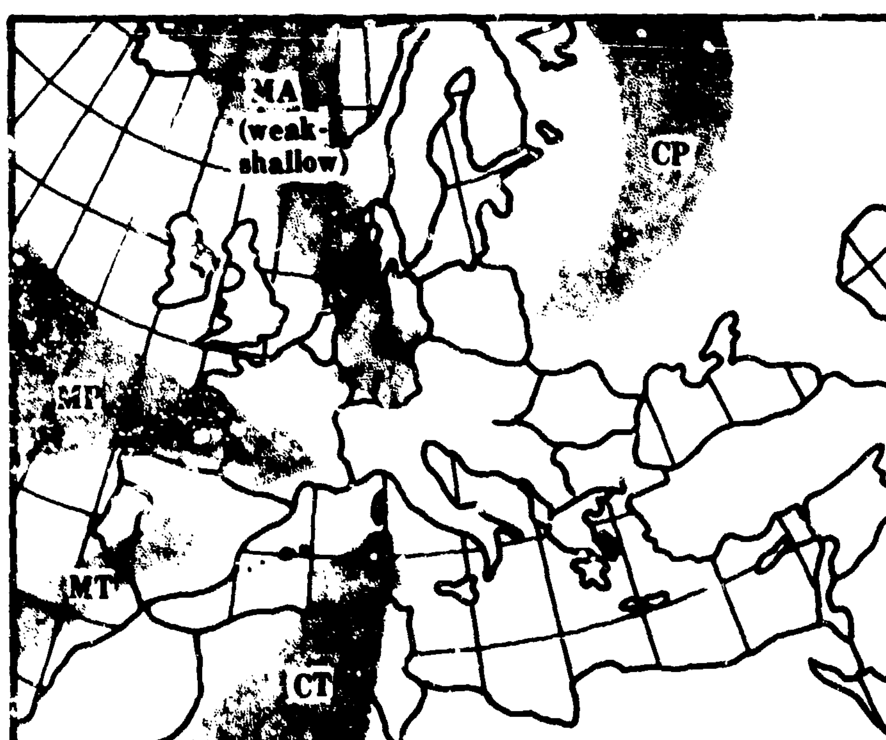

Figure 2. Trajectory of the major air masses during the summer.

Figure 3. Location of cities.

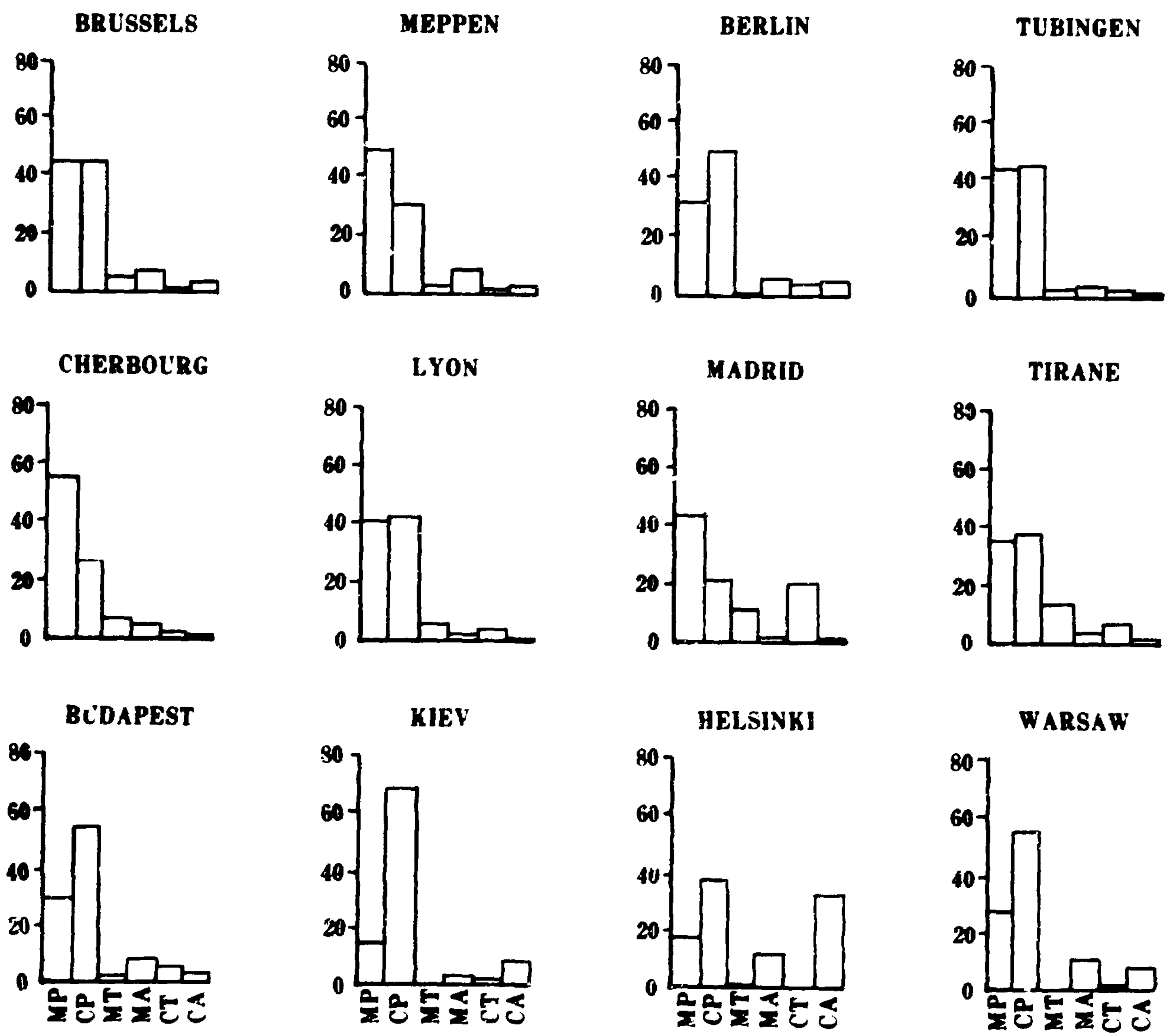

Figure 4. Frequency of occurrence of air masses over Europe during winter.

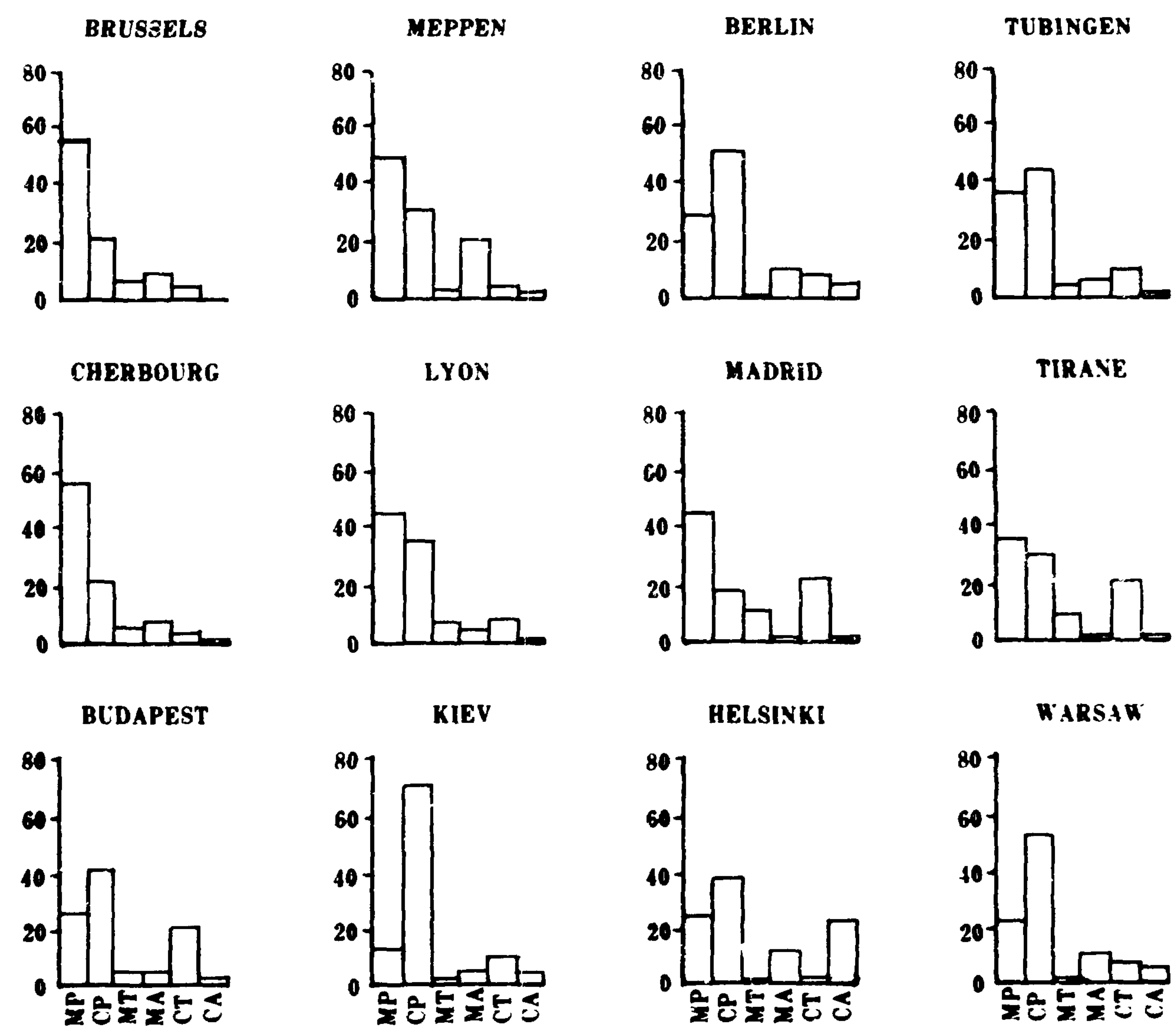

Figure 5. Frequency of occurrence of air masses over Europe during spring.

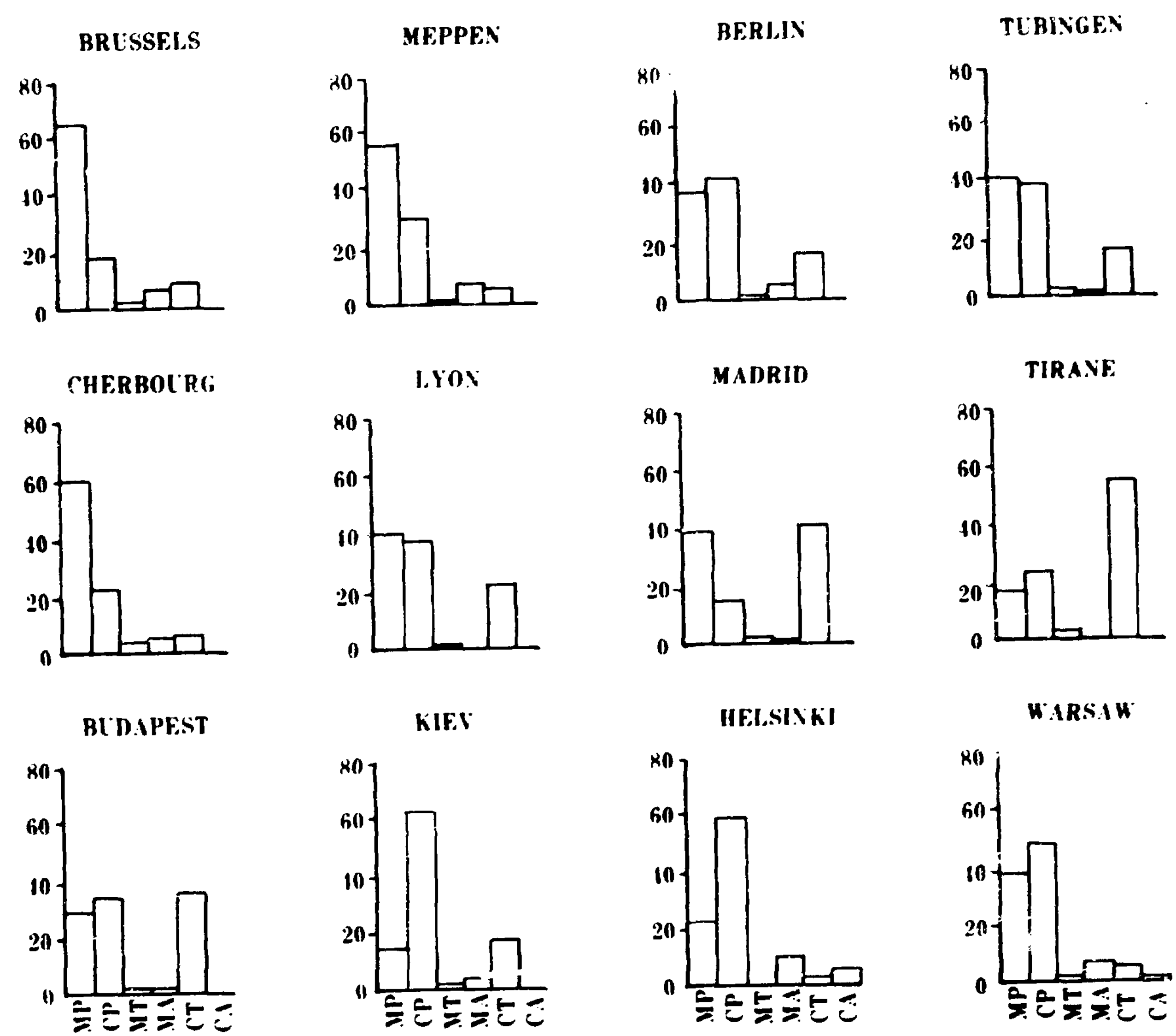

Figure 6. Frequency of occurrence of air masses over Europe during summer.

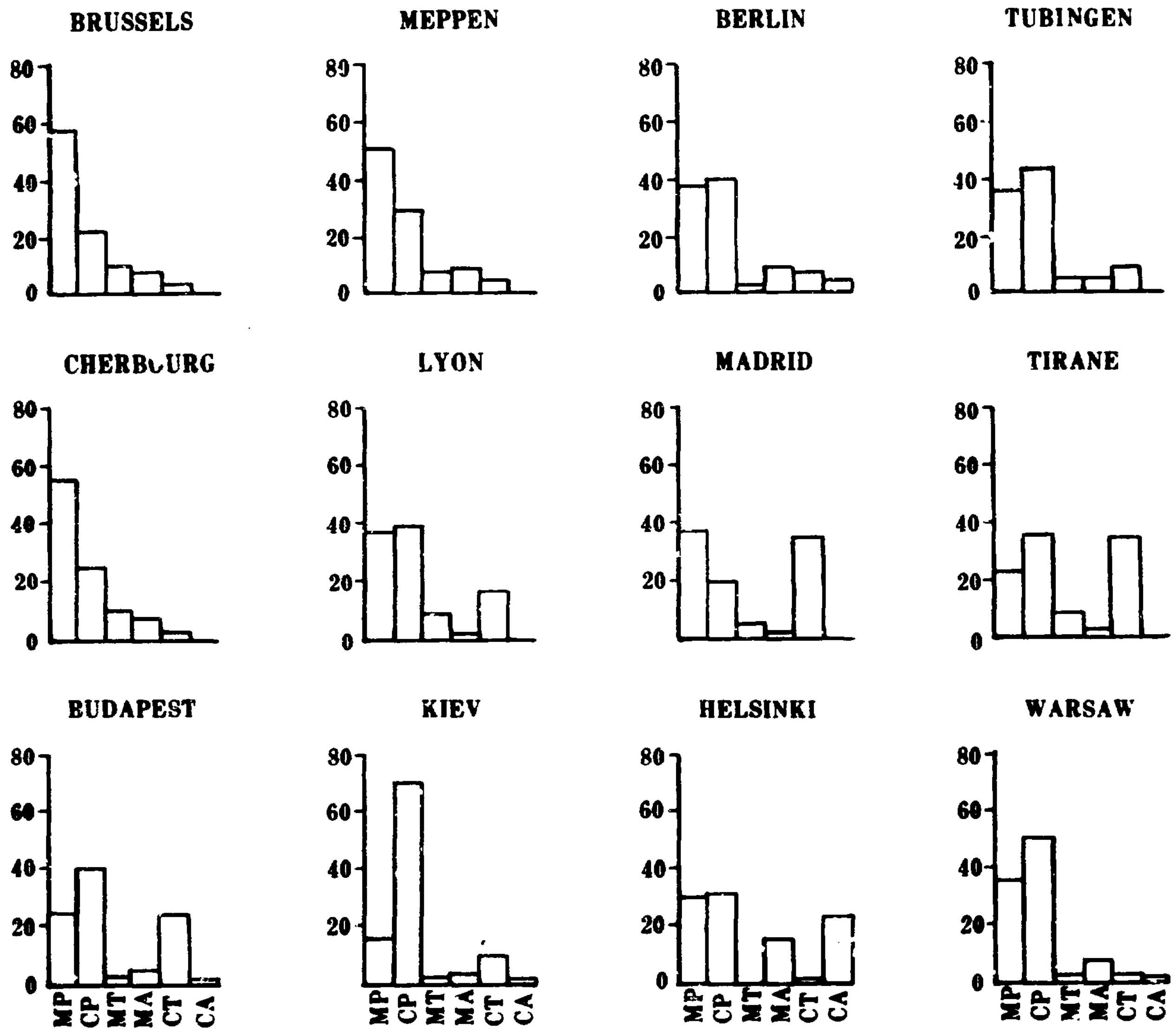

Figure 7. Frequency of occurrence of air masses over Europe during fall.

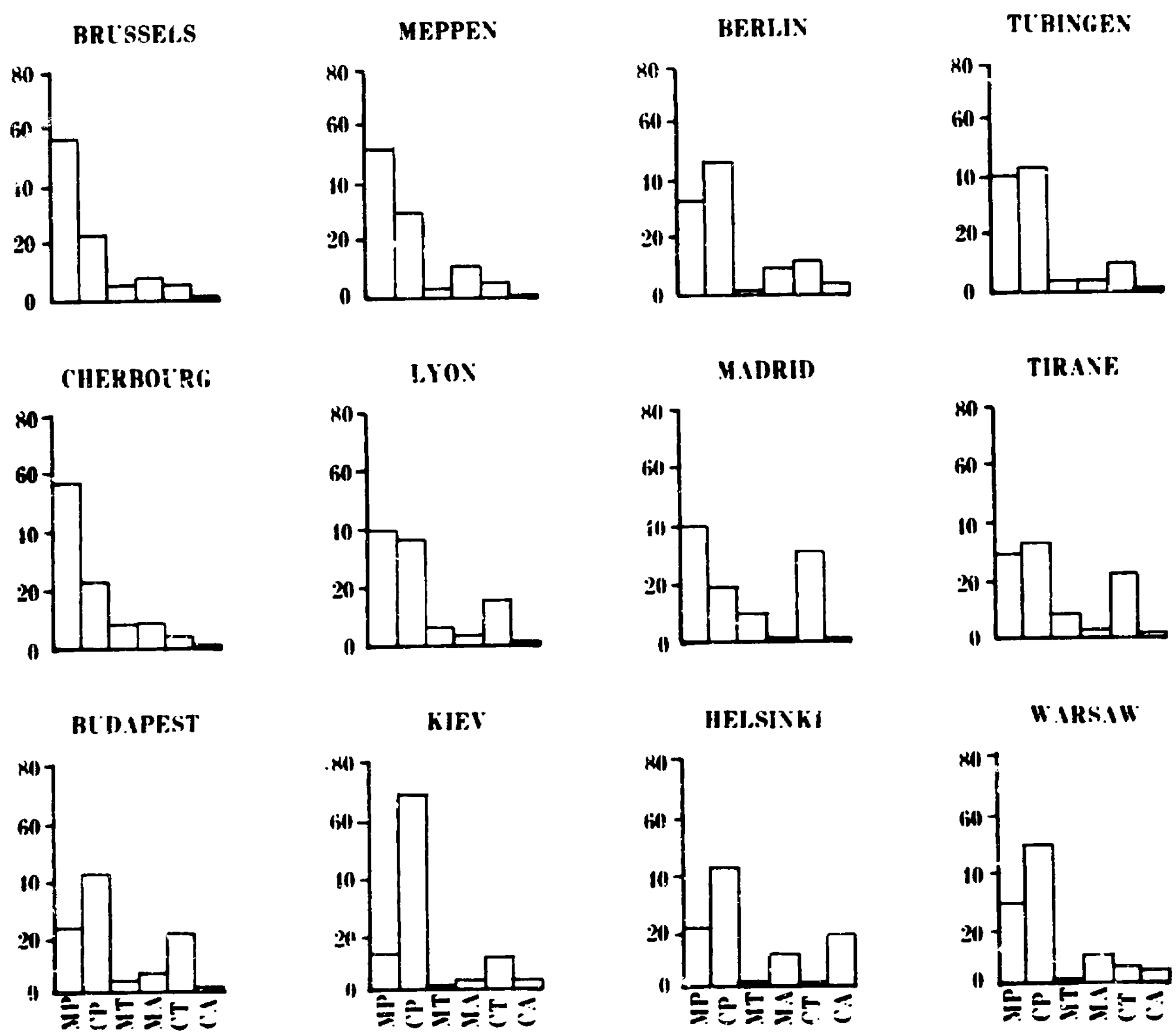

Figure 8. Annual air mass frequency of occurrence.

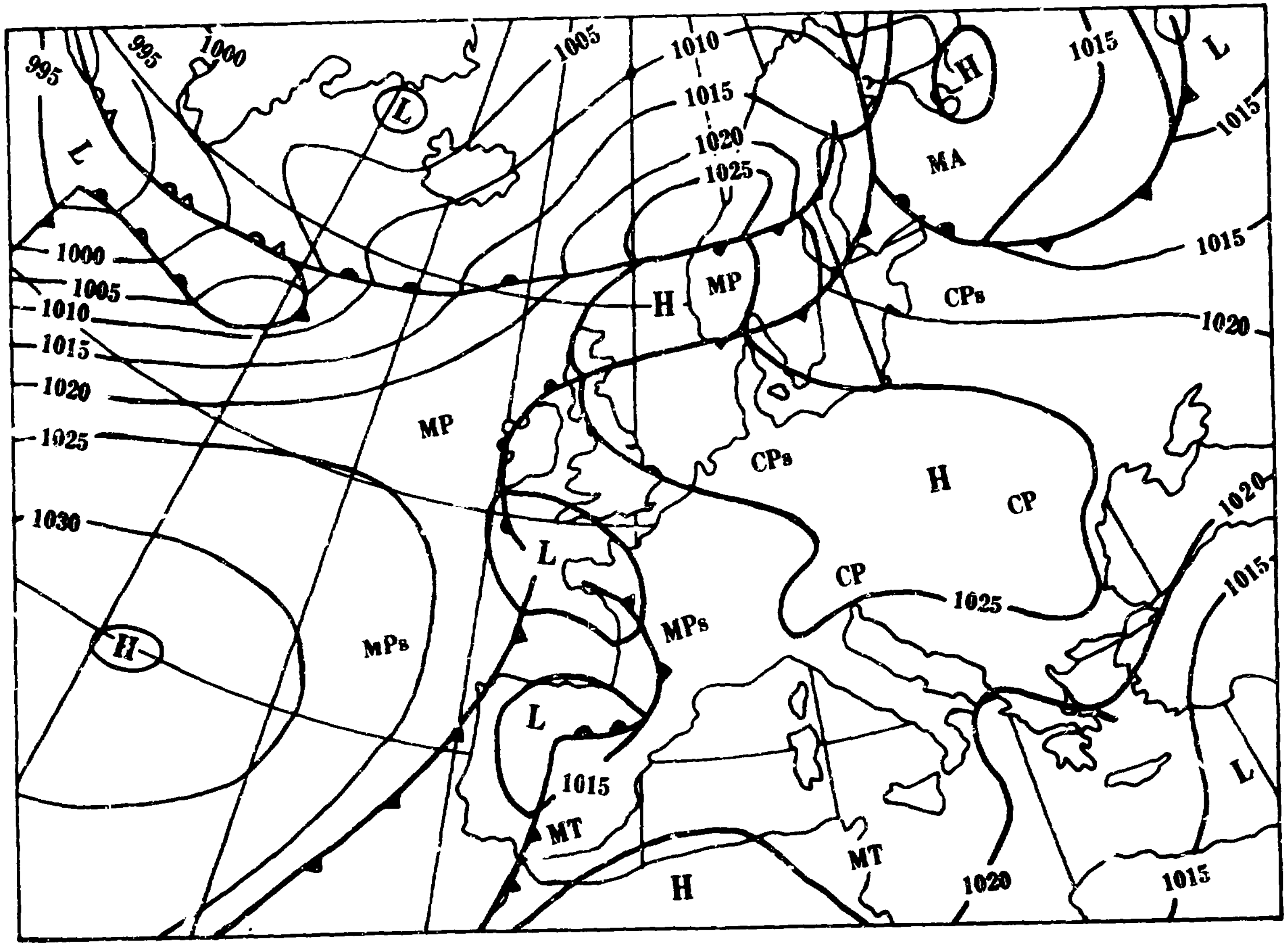

Figure 9. Typical example of HM type with indicated air masses.

TABLE 1. CLASSIFICATION OF AIR MASS AND ASSOCIATED CHARACTERISTICS

Air Mass Type	Source Region of Description	Type of Precipitation	Visibility	Stability
Continental Arctic cA	North European/ North Siberian Arctic Air	Showers in Southern Europe	Usually Good	Stable
Continental Polar cP	North European/ Russian Subpolar Air	Showers in Southern Europe	Some Haze	Stable
Continental Tropical cT	African Tropical Air	Showers as air becomes modified	Some Dust	Unstable
Maritime Arctic mA	North Sea/North Atlantic	Showers and Squalls	Good	Unstable
Maritime Polar mP	North Atlantic Subpolar/North Atlantic Sea Air	Showers	Haze and Smoke in mornings	Depends upon trajectory
Maritime Tropical mT	Southern Portion of North Atlantic	Showers	Foggy	Stable over colder land

TABLE 2. EXACT LOCATION OF CITIES AND NUMBER OF OBSERVATIONS COMPLETED

CITY	LATITUDE	LONGITUDE	NUMBER OF OBSERVATIONS	YEARS
Berlin, FRG	52.30N	13.20E	4,436	12 yrs, 4 mos
Brussels, Belgium	50.50N	4.20E	2,001	5 yrs, 6 mos
Tubingen, FRG	48.31N	9.02E	1,998	5 yrs, 6 mos
Meppen, FRG	52.41N	7.17E	1,996	5 yrs, 6 mos
Cherbourg, France	49.39N	1.39W	1,997	5 yrs, 6 mos
Budapest, Hungary	47.30N	19.05E	1,881	5 yrs, 1 mo
Madrid, Spain	40.24N	3.41E	1,876	5 yrs, 1 mo
Tirane, Albania	41.20N	19.50E	1,864	5 yrs, 1 mo
Lyon, France	45.45N	4.51E	1,806	5 yrs, 0 mos
Kiev, USSR	50.26N	30.31E	1,779	5 yrs, 0 mos
Warsaw, Poland	52.15N	21.0E	1,775	4 yrs, 11 mos
Helsinki, Finland	60.10N	24.58E	1,775	4 yrs, 11 mos

TABLE 3. MONTHLY FREQUENCY OF OCCURRENCE OF AIR MASSES AT MEPPEN, GERMANY

MONTH	mP	cP	cT	mA	mT	cA
JAN	55.2	29.5	0	9.3	1.6	4.4
FEB	44.6	39.8	2.9	7.1	2.9	2.3
MAR	55.1	27.5	1.1	4.3	5.9	5.9
APR	51.6	46.7	2.8	15.5	2.2	1.1
MAY	42.0	34.8	9.5	9.4	2.8	1.0
JUN	53.7	26.2	11.2	5.6	2.8	0
JUL	57.4	21.3	4.3	13.7	3.3	0
AUG	51.3	41.6	1.3	5.8	0	0
SEP	46.6	31.1	3.4	13.5	5.4	0
OCT	48.5	32.4	6.7	4.8	7.4	0
NOV	58.4	24.0	0	12.0	5.6	0
DEC	54.8	27.7	1.9	9.7	4.5	1.3
ANNUAL	51.5	30.1	4.0	9.2	3.6	1.5
NO OBS	1026	599	79	183	71	29

TABLE 4. MONTHLY FREQUENCY OF OCCURRENCE OF AIR MASSES AT CHERBOURG, FRANCE

MONTH	mP	cP	cT	mA	mT	cA
JAN	62.3	26.8	1.1	3.8	4.4	1.6
FEB	47.3	31.4	5.3	5.9	7.7	2.4
MAR	58.9	22.7	1.6	4.3	10.8	1.1
APR	55.8	25.1	4.5	12.8	1.7	0
MAY	54.1	24.9	6.0	9.4	5.3	0.5
JUN	60.5	25.6	7.8	2.8	2.8	0
JUL	64.5	15.9	7.1	6.0	6.6	0
AUG	61.0	31.8	1.3	3.9	1.9	0
SEP	53.4	24.3	2.0	9.5	10.8	0
OCT	60.6	41.3	6.5	2.6	9.0	0
NOV	58.4	20.8	0.8	11.2	8.8	0
DEC	53.5	27.1	2.6	7.7	8.4	1.3
ANNUAL	57.6	24.8	4.0	6.6	6.4	0.6
NO OBS	1151	495	80	132	127	12

TABLE 5. MONTHLY FREQUENCY OF OCCURRENCE OF AIR MASSES AT BRUSSELS, BELGIUM

MONTH	mP	cP	cT	mA	mT	cA
JAN	53.6	32.3	1.1	6.6	3.3	2.7
FEB	46.3	38.3	2.4	5.3	5.3	2.4
MAR	54.7	30.3	2.2	3.8	7.4	1.6
APR	61.3	18.3	4.4	13.8	1.7	0.6
MAY	59.6	16.3	8.7	9.8	4.4	1.1
JUN	61.2	20.6	10.1	3.9	4.1	0
JUL	60.1	18.0	7.1	8.7	6.0	0
AUG	75.2	14.3	2.6	2.6	5.3	0
SEP	57.1	19.7	6.4	10.2	10.2	0
OCT	60.8	21.3	1.6	1.9	6.7	0
NOV	53.4	25.5	1.4	11.1	8.7	0
DEC	41.9	38.7	1.9	9.7	6.5	1.3
ANNUAL	57.1	24.5	4.2	7.3	5.8	0.8
NO OBS	1134	503	88	145	113	17

TABLE 6. MONTHLY FREQUENCY OF OCCURRENCE OF AIR MASSES AT BERLIN, GERMANY

MONTH	mP	cP	cT	mA	mT	cA
JAN	25.0	55.9	5.9	0.3	0.3	6.7
FEB	28.7	54.8	4.1	0.6	0.6	3.9
MAR	31.7	49.5	4.3	1.3	1.3	7.3
APR	23.3	47.7	6.7	1.0	1.0	4.9
MAY	26.1	49.9	14.0	0.3	0.3	1.5
JUN	33.4	40.0	21.0	0.8	0.8	0
JUL	39.5	39.5	14.8	1.2	1.2	0
AUG	36.3	45.2	12.6	1.6	1.6	0
SEP	37.0	37.3	9.5	3.3	3.3	2.5
OCT	32.3	45.2	9.1	2.1	2.1	3.2
NOV	37.9	36.4	5.2	1.8	1.8	7.6
DEC	39.6	40.1	5.0	0.9	0.9	7.9
ANNUAL	32.6	45.1	9.3	7.9	1.3	3.8
NO OBS	1438	2003	424	352	56	163

TABLE 7. MONTHLY FREQUENCY OF OCCURRENCE OF AIR MASSES AT TUBINGEN, GERMANY

MONTH	mP	cP	cT	mA	mT	cA
JAN	51.4	38.8	1.1	3.3	2.7	2.7
FEB	40.3	47.9	5.9	3.6	1.8	0
MAR	48.2	36.7	5.4	1.6	4.2	3.8
APR	34.7	46.9	7.3	8.9	1.7	0.6
MAY	29.9	48.4	13.0	4.6	3.3	0.6
JUN	40.3	33.0	24.0	1.7	1.1	0
JUL	43.1	29.5	18.0	3.8	5.5	0
AUG	35.7	54.5	5.8	0.6	3.3	0
SEP	32.7	46.2	13.6	4.1	3.4	0
OCT	36.8	40.0	12.3	1.9	9.0	0
NOV	35.2	46.4	1.3	12.0	4.8	0
DEC	39.3	48.4	1.3	5.8	5.2	0
ANNUAL	40.0	42.8	9.1	4.1	3.8	0.6
NO OBS	775	853	188	83	85	14

TABLE 8. MONTHLY FREQUENCY OF OCCURRENCE OF AIR MASSES AT LYON, FRANCE

MONTH	mP	cP	cT	mA	mT	cA
JAN	45.3	43.3	2.0	3.4	4.7	1.3
FEB	43.2	42.5	6.5	0.7	7.2	0
MAR	54.2	37.3	1.9	0	5.3	1.9
APR	41.3	38.8	9.2	6.7	3.3	0.6
MAY	38.7	35.8	15.5	3.2	6.8	0
JUN	42.1	29.6	25.0	0.7	2.5	0
JUL	37.7	32.5	25.7	1.4	2.7	0
AUG	38.2	42.2	15.0	2.6	2.0	0
SEP	27.5	42.0	25.8	1.3	3.4	0
OCT	40.0	37.1	16.8	0.6	5.5	0
NOV	40.0	44.6	4.2	5.8	5.4	0
DEC	40.5	45.3	3.2	2.4	8.7	0
ANNUAL	40.7	39.2	12.6	2.4	5.0	0.3
NO OBS	736	680	234	43	109	6

TABLE 9. MONTLY FREQUENCY OF OCCURRENCE OF AIR MASSES AT WARSAW, POLAND

MONTH	mP	cP	cT	mA	mT	cA
JAN	27.0	54.9	0	10.6	0	7.5
FEB	28.9	63.4	2.1	3.5	0	2.1
MAR	34.9	43.6	3.4	5.4	2.0	10.7
APR	23.4	57.2	1.7	13.6	0	4.0
MAY	15.4	59.5	12.4	9.5	1.3	2.0
JUN	35.9	44.8	12.4	4.8	1.4	0.7
JUL	39.7	47.5	3.3	7.8	1.7	0
AUG	37.5	54.4	1.3	6.1	0.7	0
SEP	36.6	44.1	2.8	13.4	1.8	1.4
OCT	27.6	58.1	3.9	5.2	3.9	1.3
NOV	35.5	50.0	3.2	6.4	1.6	3.2
DEC	32.0	45.9	0.8	9.0	0.8	11.5
ANNUAL	31.2	51.9	2.9	7.9	1.3	3.7
NO OBS	552	924	71	142	22	63

TABLE 10. MONTHLY FREQUENCY OF OCCURRENCE OF AIR MASSES AT HELSINKI, FINLAND

MONTH	mP	cP	cT	mA	mT	cA
JAN	19.7	40.3	0	11.8	1.4	26.7
FEB	14.6	47.8	0.7	9.6	0.7	26.4
MAR	24.4	31.4	0	8.2	0.7	35.2
APR	30.2	32.2	0.3	13.5	0	23.7
MAY	17.8	44.0	4.6	16.4	0	17.1
JUN	23.9	51.0	6.2	6.2	0	12.5
JUL	30.4	60.4	2.3	6.2	0	0.6
AUG	22.2	62.4	0	11.4	0	3.9
SEP	26.6	31.4	0.6	23.6	0	17.5
OCT	26.3	33.5	1.3	10.5	0	28.3
NOV	36.9	27.6	0.8	15.4	0	19.1
DEC	22.9	25.0	0	11.0	0.8	40.2
ANNUAL	24.7	41.2	1.4	12.0	0.3	20.3
NO OBS	440	731	25	212	5	361

TABLE 11. MONTHLY FREQUENCY OF OCCURRENCE OF AIR MASSES AT KIEV, USSR

MONTHLY	mP	cP	cT	mA	mT	cA
JAN	14.0	58.6	1.4	4.7	1.4	9.5
FEB	17.3	79.2	0.7	0	0	3.5
MAR	17.7	69.0	3.4	3.4	1.0	5.4
APR	11.7	73.9	5.1	3.4	1.7	4.0
MAY	4.5	70.9	17.0	3.2	2.3	1.9
JUN	15.2	62.0	22.1	1.0	0	0
JUL	17.1	59.3	16.2	3.4	2.8	1.1
AUG	13.5	66.9	16.2	2.6	0.7	0
SEP	13.8	64.2	15.6	4.2	1.9	0.7
OCT	10.6	79.2	7.3	1.6	1.3	0.6
NOV	19.1	63.3	5.9	2.5	3.8	4.2
DEC	18.0	62.6	2.8	6.5	0	9.8
ANNUAL	14.4	68.3	9.5	3.0	1.4	3.4
NO OBS	253	1214	172	54	25	60

TABLE 12. MONTHLY FREQUENCY OF OCCURRENCE OF AIR MASSES AT MADRID, SPAIN

MONTH	mP	cP	cT	mA	mT	cA
JAN	37.4	20.0	28.4	0	11.9	2.6
FEB	43.7	24.6	19.0	1.0	12.0	0
MAR	44.6	16.5	25.5	0.6	12.1	0.6
APR	45.9	17.3	25.4	2.7	8.1	0.5
MAY	49.0	16.8	21.5	2.0	8.7	0
JUN	47.8	14.5	33.9	1.7	2.2	0
JUL	31.0	15.2	47.8	0.5	5.4	0
AUG	37.0	13.0	47.4	0.6	2.0	0
SEP	25.2	19.2	51.0	0.6	4.0	0
OCT	47.8	14.8	28.4	0.6	8.4	0
NOV	40.8	29.1	21.7	4.2	4.2	0
DEC	52.8	16.6	17.4	0.7	12.5	0
ANNUAL	41.9	18.0	31.1	1.2	7.5	0.3
NO OBS	786	337	584	23	141	6

TABLE 13. MONTHLY FREQUENCY OF OCCURRENCE OF AIR MASSES AT BUDAPEST, HUNGARY

MONTH	mP	cP	cT	mA	mT	cA
JAN	23.4	55.8	3.9	9.1	2.6	5.2
FEB	29.8	55.3	5.7	5.7	1.4	2.1
MAR	35.5	35.5	16.8	1.3	5.2	5.8
APR	25.1	44.7	21.8	3.3	3.3	1.7
MAY	17.0	43.7	28.8	7.7	3.2	0
JUN	23.9	40.0	40.6	0.5	0	0
JUL	27.7	39.2	31.0	0.5	1.6	0
AUG	23.2	37.4	38.1	0.6	0.6	0
SEP	22.0	42.0	29.3	6.0	0.7	0
OCT	25.8	34.9	35.5	1.3	2.6	0
NOV	33.4	45.0	10.0	7.5	2.5	1.7
DEC	31.2	48.4	7.1	5.8	2.6	3.9
ANNUAL	26.4	43.5	22.4	3.9	2.2	1.7
NO OBS	497	805	433	73	41	31

TABLE 14. MONTHLY FREQUENCY OF OCCURRENCE OF AIR MASSES AT TIRANE, ALBANIA

MONTH	mP	cP	cT	mA	mT	cA
JAN	27.7	46.5	3.2	6.4	12.3	3.9
FEB	46.2	29.4	8.4	2.1	13.3	0.7
MAR	42.6	21.3	13.5	1.9	18.1	2.6
APR	43.8	26.4	20.8	1.1	6.7	1.1
MAY	17.3	43.4	33.8	0.7	4.8	0
JUN	17.2	23.4	55.0	0	4.4	0
JUL	16.9	32.6	47.3	0	3.3	0
AUG	15.7	21.8	61.9	0	0.7	0
SEP	17.4	30.9	47.0	2.7	2.0	0
OCT	18.2	35.0	32.5	2.6	11.7	0
NOV	40.4	33.6	14.3	1.7	10.1	0
DEC	35.5	42.5	12.3	2.6	5.8	1.3
ANNUAL	28.2	32.3	29.2	1.8	7.7	0.8
NO OBS	520	597	557	33	142	15

TABLE 15. SEASONAL FREQUENCY OF OCCURRENCE OF AIR MASSES

SEASON	mP	cP	cT	mA	mT	cA
			MEPPEN, GERMANY			
WINTER	51.6	32.4	1.6	8.6	3.0	2.7
SPRING	49.6	29.7	4.6	9.7	3.7	2.7
SUMMER	54.1	29.3	5.8	8.5	2.0	0
FALL	51.7	29.4	3.6	10.0	6.1	0
			TUBINGEN, GERMANY			
WINTER	44.0	44.8	2.8	4.1	3.1	1.0
SPRING	37.6	43.7	8.5	5.4	3.1	1.6
SUMMER	39.9	38.2	16.5	2.1	3.3	0
FALL	34.9	44.0	9.6	5.6	5.8	0
			BRUSSELS, BELGIUM			
WINTER	47.3	36.4	1.8	7.1	4.9	2.2
SPRING	58.5	21.6	5.1	9.1	4.5	1.1
SUMMER	65.5	17.9	6.8	5.2	5.1	0
FALL	57.0	21.9	3.7	7.7	8.5	0
			CHERBOURG, FRANCE			
WINTER	54.6	28.4	2.9	5.7	6.7	1.8
SPRING	56.4	24.3	4.0	8.8	5.9	0.6
SUMMER	62.1	24.0	5.6	4.4	3.9	0
FALL	57.4	22.2	3.3	7.5	9.6	0

TABLE 16. SEASONAL FREQUENCY OF OCCURRENCE OF AIR MASSES

SEASON	mP	cP	cT	mA	mT	cA
			LYON, FRANCE			
WINTER	42.8	43.7	4.0	2.1	6.6	0.5
SPRING	44.5	37.3	8.8	3.5	5.1	0.8
SUMMER	39.1	34.9	22.1	1.4	2.3	0
FALL	35.8	41.2	16.5	2.4	4.8	0
			WARSAW, POLAND			
WINTER	29.0	55.2	1.0	7.6	0.2	6.8
SPRING	24.5	53.8	5.7	9.7	1.1	5.5
SUMMER	37.8	48.7	5.5	6.3	1.3	0.2
FALL	32.9	51.0	3.3	8.3	2.4	1.9
			HELSINKI, FINLAND			
WINTER	19.0	38.1	0.2	11.0	1.0	30.5
SPRING	24.6	35.7	1.7	12.7	0.2	24.9
SUMMER	25.9	58.5	2.7	8.0	0	5.3
FALL	29.6	31.3	0.9	16.3	0	21.7
			KIEV, USSR			
WINTER	16.3	70.6	1.7	3.5	0.5	7.5
SPRING	11.3	71.5	8.4	3.3	1.7	3.8
SUMMER	15.5	62.1	18.0	2.5	1.3	0.4
FALL	14.0	69.3	9.9	2.9	2.4	1.7

TABLE 17. SEASONAL FREQUENCY OF OCCURRENCE OF AIR MASSES

SEASON	mP	cP	cT	mA	mT	cA
			BERLIN, GERMANY			
WINTER	30.9	50.4	5.0	6.9	0.6	6.2
SPRING	26.9	49.0	8.4	10.2	0.9	4.5
SUMMER	36.2	41.4	16.2	4.8	1.2	0
FALL	35.6	39.7	8.0	9.9	2.5	4.3
			TIRANE, ALBANIA			
WINTER	35.8	37.2	7.7	4.2	13.0	2.0
SPRING	35.3	29.9	22.4	1.3	9.8	1.3
SUMMER	17.9	23.7	55.4	0	2.9	0
FALL	24.1	33.2	32.4	2.3	7.8	0
			MADRID, SPAIN			
WINTER	44.4	20.3	21.7	0.7	12.0	0.9
SPRING	46.4	17.5	24.2	1.8	9.6	0.4
SUMMER	38.6	14.3	42.8	1.0	3.3	0
FALL	37.8	20.5	34.5	1.6	5.6	0
			BUDAPEST, HUNGARY			
WINTER	28.4	53.1	5.5	6.9	2.2	3.8
SPRING	25.8	41.4	22.4	3.9	3.9	2.5
SUMMER	24.7	35.2	38.5	0.6	0.9	0
FALL	26.6	40.2	26.1	4.7	1.9	0.5

TABLE 18. ANNUAL AIR MASS FREQUENCY OF OCCURRENCE STATISTICS

CITY	mP	cP	cT	mA	mT	cA
Meppen	51.5	30.1	4.0	9.2	3.6	1.5
Cherbourg	57.6	24.8	4.0	6.6	6.4	0.6
Brussels	57.1	24.5	4.5	7.3	5.8	0.9
Tubingen	40.0	42.7	9.1	4.1	3.8	0.6
Lyon	40.7	39.2	12.6	2.4	5.0	0.3
Warsaw	31.1	51.9	2.9	7.9	1.3	3.7
Helsinki	24.7	41.2	1.4	12.0	0.3	20.3
Kiev	14.4	68.3	9.5	3.0	1.4	3.4
Berlin	32.6	45.1	9.3	7.9	1.3	3.8
Madrid	41.9	18.0	31.1	1.2	7.5	0.3
Budapest	26.4	43.5	22.4	3.9	2.2	1.7
Tirane	28.2	32.3	29.2	1.8	7.7	0.8

LITERATURE CITED

1. Shirkey, R. C., and S. G. O'Brien, editors, 1981, EOSAEL 80 Volume II User's Manual, ASL-TR-0073, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM.

2. Steinhoff, R. G., 1981, Supplement to EOSAEL 80 Volume II User's Manual, Program Listings for EOSAEL 80 and Ancillary Codes AGAUS and FLASH, ASL-TR-0073 (Supplement), US Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM.

3. Duncan, Louis D., and James D. Lindberg, 1981, Air Mass Considerations in Fog Optical Modeling, ASL-TR-0075, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM, 1981.

4. Berry, F. A., E. Bollay and Norman R. Beers, 1945, Handbook of Meteorology, McGraw Hill Book Co, Inc, New York.

5. Petterssen, Sverre, 1940, Weather Analysis and Forecasting, McGraw Hill Book Co, Inc, New York.

6. Byers, Horace Robert, 1944, General Meteorology, McGraw Hill Book Co, Inc, New York.

7. Willett, Hurd C., 1944, Descriptive Meteorology, Academic Press, Inc, New York.

8. Haurwitz, Bernhard, and James M. Austin, 1944, Climatology, McGraw Hill Book Co, Inc, New York.

9. Jewell, Ralph, 1981, "The Bergen School of Meteorology," Bull of Amer Met Soc, Vol 62.

10. Bergeron, T., 1928, "Uber die Dreieimensional Verknupfende Wetteranalyse, Geof Pub, Vol V.

11. Bergeron, T., 1930, "Richtlinien einer Dynamischen Klimatogie," Met Zeitscher.

12. Pruppacher, Hans R., and James D. Klett, 1978, Microphysics of Clouds and Precipitation, D. Reider Publishing Co., Dortrecht, Holland.

13. Twomey, S., and T. A. Wojciechowski, 1969, "Observations of the Geographical Variation of Cloud Nuclei," J Atmos Sci, Vol 26.

14. Rosenthal, J., et al, 1979, "Summary Marine/Continental History of Aerosols at San Nicolas Island During CEWCOM-78 and OSP III," TP-79-32, Pacific Missile Test Center, Point Mugu, CA.

15. Gothman, S. G., and G. G. Julian, 1980, Passive 19.3 GHz Radiometer and Aerosol Data From the North Sea During MARSEN I, Sep-Oct 1979, NRL Memo Report 4285, Navy Research Laboratory, Washington, DC.

16. Fitch, Bruce W., and Ted S. Cress, 1981, Measurements of Aerosol Size Distribution in the Lower Troposphere Over Northern Europe, AFGL-TR-80-0192, University of California at San Diego, Scripps Institute of Oceanography, Visibility Laboratory, SIO Ref 81-18, 1981.

17. Deirmendjian, D., 1980, Aerosol Modelling for Optical Weather, Final Report, Rand Corporation, US Army Research Office, Durham, NC.

18. Barrett, E. W., F. B. Parungo and R. F. Pueschel, 1979, "Cloud Modification by Urban Pollution: A Physical Demonstration," Meteorol Rundschau, Vol 32.

19. Kireyeva, N. M., G. B. Mashkova and N. P. Yasevich, 1976, Change in the Concentration of Atmospheric Aerosols with the Passage of Fronts, Trudy Institut Eksperimental Noy Meteorologei, Seriya Fizika Nizhney Atmosfery, Issue 12(31), Moscow, ADB051552, trans Foreign Tech Div.

20. Buma, T. J., 1960, "A Statistical Study of the Relationship Between Visibility and Relative Humidity at Leeuwarden," Bull Amer Met Soc, Vol 41.

21. Van de Van, M. J. M., 1978, Aerosol Measurements During Spring 1978: Their Size Distributions and Optical Properties in Visible and Infrared Wavelength Regions, Report PHL 1978-41, Physics Laboratory of the National Defense Organization TNO, The Hague, Netherlands.

22. Low, R. D. H., 1968, "A Comprehensive Report on Nineteen Condensation Nuclei and Aerosol Particles as a Function of Its Dry Size and Composition and the Relative Humidity," J Appl Meteorol, Vol 14.

23. Hanel, Gottfried, 1976, "The Properties of Atmospheric Aerosol Particles as Functions of the Relative Humidity at Thermodynamic Equilibrium with the Surrounding Moist Air," Advan in Geophys, Vol 19, Academic Press, New York.

24. Fitzgerald, J. W., 1975, "Approximation Formulas for the Equilibrium Size of an Aerosol Particle as a Function of its Dry Size and Composition and the Relative Humidity," J Appl Meteorol, Vol 14.

25. Lindberg, James D., 1981, "Atmospheric Effects on Electro-Optical, Infrared, and Millimeter Wave Systems Performance," Proceedings of SPIE - The International Society for Optical Engineering, Vol 305, (Bellingham, WA: Society of Photo-Optical Instrumentation Engineers).

26. Nilsson, Bertil, 1979, "Meteorological Influence on Aerosol Extinction in the 0.2 - 40μm Wavelength Range," Appl Opt, Vol 18.

27. Pinnick, R. G., et al, 1978, "Vertical Structure in Atmospheric Fog and Haze and Its Effects on Visible and Infrared Extinction," J Atmos Sci, Vol 35.

28. Geb, M., 1973, Die Anwendung der Objektivierten Luftmassen-Klassifikation für Mitteleuropa, Beilage zur Berliner Wetterkarte, des Instituts für Meteorologie, der Freien Universitat Berlin, Berlin, FRG.

29. Essenwanger, Oskar, 1954, Neue Methode der Zerlegung von Haufigkeitsverteilungen, in Gauß' sche Normalkurven und ihre Anwendung in der Meteorologie, Berichte des Deutschen Wetterdienstez, Nr 10.

30. Bryson, Reid A., 1966, "Air Masses, Streamlines, and the Boreal Forest," Geographical Bulletin, Vol 8.

31. Davis, J. M., 1981, The Use of Cluster Analysis in the Identification and Characterization of German Air Masses, Internal Report, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM.

32. Showalter, A. K., 1939, "Further Studies of American Air Mass Properties, Monthly Weather Rev, Vol 67.

33. McIntyre, D. P., 1950, "On the Air Mass Temperature Distribution in the Middle and High Troposphere in Winter," J Meteorol, Vol 7.

34. Berggren, R., 1953, "On Temperature Frequency Distribution in the Free Atmosphere and a Proposed Model for Frontal Analysis," Tellus, Vol 5.

35. McDonald, N. S., 1975, "Eigenvector Analysis as an Aid to Air Mass Recognition," Arch Meteorol Geophys Bioklimatol, A, Vol 24.

36. Coleman, Cranston R., 1982, "An Interactive Computer Technique for Separating Mixed Normal Distributions Applied to Air Mass Analysis," Masters Thesis submitted to North Carolina State University, Raleigh, NC.

37. Catalogue of European Large Scale Weather Types From a Report of the German Weather Service in the US Zone No 33, Bad Kissingen, 1952, as Revised by 2nd Weather Wing, Military Airlift Command, US Air Force, 1968.

38. Essenwanger, O. M., 1973, On the Duration of Widespread Fog and Low Ceiling in Central Europe and Some Aspects of Predictability, TR-RR-73-9, US Army Missile Command, Redstone Arsenal, AL.

SELECTED BIBLIOGRAPHY

Basic Smoke Characterization - Phase I, 1978, Final Test Report, DPG-TP-77-311, Dugway Proving Ground, UT.

Blanc, Theodore V., 1980, The Marine Surface Layer Micrometeorological Experiment at San Nicolas Island, CA.

Deirmendjian, D., 1960, "Atmospheric Extinction of Infrared Radiation," Quart J Roy Meteorol Soc, Vol 86.

DPG Final Test Report on Smoke Week II at Eglin AFB, FL, (U), Confidential, 1978, Vols I and II, DPG-FR-78-317, Dugway Proving Ground, UT.

Duntley, S. Q., 1947, "The Visibility of Objects Seen Through the Atmosphere," J Opt Soc Am, Vol 37.

Duntley, S. Q., R. W. Johnson and J. I. Gordon, 1976, Airborne Measurements of Optical Atmospheric Properties in Northern Germany, AFGL-TR-76-0188, Visibility Laboratory, University of California, La Jolla, CA.

Dust/Debris Field Test Add-on, 1979, DPG-FR-78-313 Add-on, Dugway Proving Ground, UT.

Dust/Debris Test Conducted at Fort Sill, OK, by DPG, 1978, Final Test Report, Vols I and II, DPG-FR-78-313, Dugway Proving Ground, UT.

Dust Trial Phase of Inventory Smoke Munition Test - Phase IIa, 1978, Final Test Report, DPG-FR-77-314, Dugway Proving Ground, UT.

Ebersole, John F., et al, 1980, Analysis and Modeling of the DIRT-I and Graf II Battlefield Dust Obscuration Data, ASL-CR-80-1137-1, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM.

Fenn, Robert W., 1978, OPAQUE - A Measurement Program on Optical Atmospheric Properties in Europe, Vol I--The NATO OPAQUE Program, AFGL-TR-78-0011, Air Force Geophysics Laboratory, Hanscom AFB, MA.

Fitch, Bruce W., and Ted S. Cress, 1981, Measurements of Aerosol Size Distribution in the Lower Troposphere Over Northern Europe, AFGL-TR-80-0192, Air Force Geophysics Laboratory, Hanscom AFB, MA.

Foreign Smoke Munitions Test - Phase III, 1978, Final Test Report, Vols I and II, DPG-FR-77-316, Dugway Proving Ground, UT.

Gotham, S. G., and B. G. Julian, 1980, Passive 19.3 GHz Radiometer and Aerosol Data from the North Sea During MARSEN I, Sept-Oct 1979, NRL Report 4265, Naval Research Laboratory, Washington, DC.

Gomez, Richard B., 1972, Atmospheric Effects for Ground Target Signature Modeling, ECOM-5445, US Army Electronics Command, Fort Monmouth, NJ.

Gruenzel, Ronald R., Personal Communication. EO Sensor/Atmospheric Science Group, Mission Avionics Division, Avionics Laboratory, Wright-Patterson AFB, Ohio.

High Humidity Hygroscopic Smoke Test, 1980, Final Test Report, Vols I and II, DPG-FR-79-310, Dugway Proving Ground, UT.

Inventory Smoke Munitions Test--Phase IIa, 1978, Final Test Report, Vols I and II, DPG-FR-77-311, Dugway Proving Ground, UT.

Johnson, Richard W., et al, 1979, Preliminary Analysis and Modelling Based Upon Project OPAQUE Profile and Surface Data, AFGL-TR-79-0285, Visibility Laboratory, Unviersity of California, La Jolla, CA.

Junge, C. E., 1963, Air Chemistry and Radio-Activity, Academic Press, New York.

Kennedy, Bruce W., 1981, Battlefield Inducted Contamination Test, Internal Report, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM.

Kennedy, Bruce W., 1980, Dusty Infrared Test-II (DIRT-II Program), ASL-TR-0058, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM.

Kennedy, Bruce W., 1981, Dusty Infrared Test-III (DIRT-III) Project Summary, Internal Report, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM.

Lindberg, James D., 1979, Measured Effects of Battlefield Dust and Smoke on Visible, Infrared, and Millimeter Wavelength Propagation, A Preliminary Report on Dusty Infrared Test-I (DIRT-I), ASL-TR-0021, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM.

Lujetic, Victor J., 1979, A Report on Atmospheric Obstructions to Visibility, Volume II--Results of Literature Search, RC-168-001, US Army Engineer Topographic Laboratories, Fort Belvoir, VA.

Maddix, M., et al, 1981, BELDWSS Phase III Field Test Data, TADS Tracking Performance in Battlefield Environments, (U), Confidential, SR-RG-81-3 to 9, US Army Missile Command, Redstone Arsenal, AL.

Middleton, W. E. K., 1952, Vision Through the Atmosphere, University of Toronto Press, Toronto, Canada.

Moulton, J., et al, 1980, Grafenwohr II, Realistic Battlefield Trials, (U), Confidential, DELNV-TR-0013, Night Vision and Electro-Optics Laboratory, Fort Belvoir, VA.

Raby, John W., 1980, "A Comparison of Modeled and Observed Aerosol Distributions and Extinction During Late Summer in the Northeast Atlantic Ocean," Master's Thesis, Naval Postgraduate School.

Rosenthal, S., et al, 1979, Marine/Continental History of Aerosols at San Nicolas Island During DEWCOM-78 and OSP III, TP-79-32, Pacific Missile Test Center, Point Mugu, CA.

Roy, E. L., and G. A. Emmons, 1965, A Literature Survey on the Atmospheric Effects on the Propagation of 1.06 Micron Laser Radiation, RE-TR-65-3, Electromagnetics Laboratory, US Army MICOM, Redstone Arsenal, AL.

Smallay, H. M., 1981, Final Report, Smoke Week III (SW III), DPG-FR-80-305, Dugway Proving Ground, UT.

Smoke Test of the Grenade, PR L8A1--Phase IIb, 1978, Final Test Report, Vols I and II, DPG-FR-315, Dugway Proving Ground, UT.

Smoke Week I, Electro-Optical Systems Performance in Characterized Smoke Environment at Dugway Proving Ground, UT, Nov 77, (U), Confidential, DRPCM-SMK-T-002-78, Project Manager, Smoke/Obscurants, 1978, Aberdeen Proving Ground, MD.

Talley, E. H., 1981, Final Report, Phase III, AAH/Hellfire Battlefield Obscuration Program, Teledyne Brown Engineering, SD81-MICOM-2534, for US Army Missile Command, Huntsville, AL.

Van de Hulst, H. D., 1957, Light Scattering by Small Particles, John Wiley and Sons, New York.

Van der Laan, J. E., 1979, Lidar Observations at 0.7 km and 10.6μm Wavelengths During Dusty Infrared Test I (DIRT-I), ASL-CR-79-0001-2, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM.